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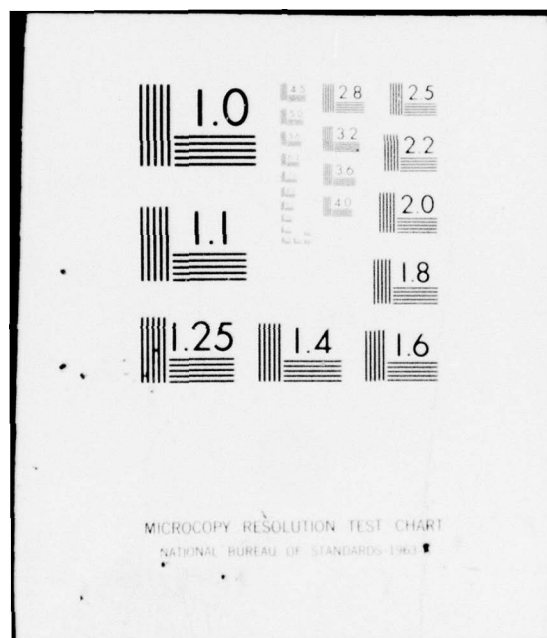
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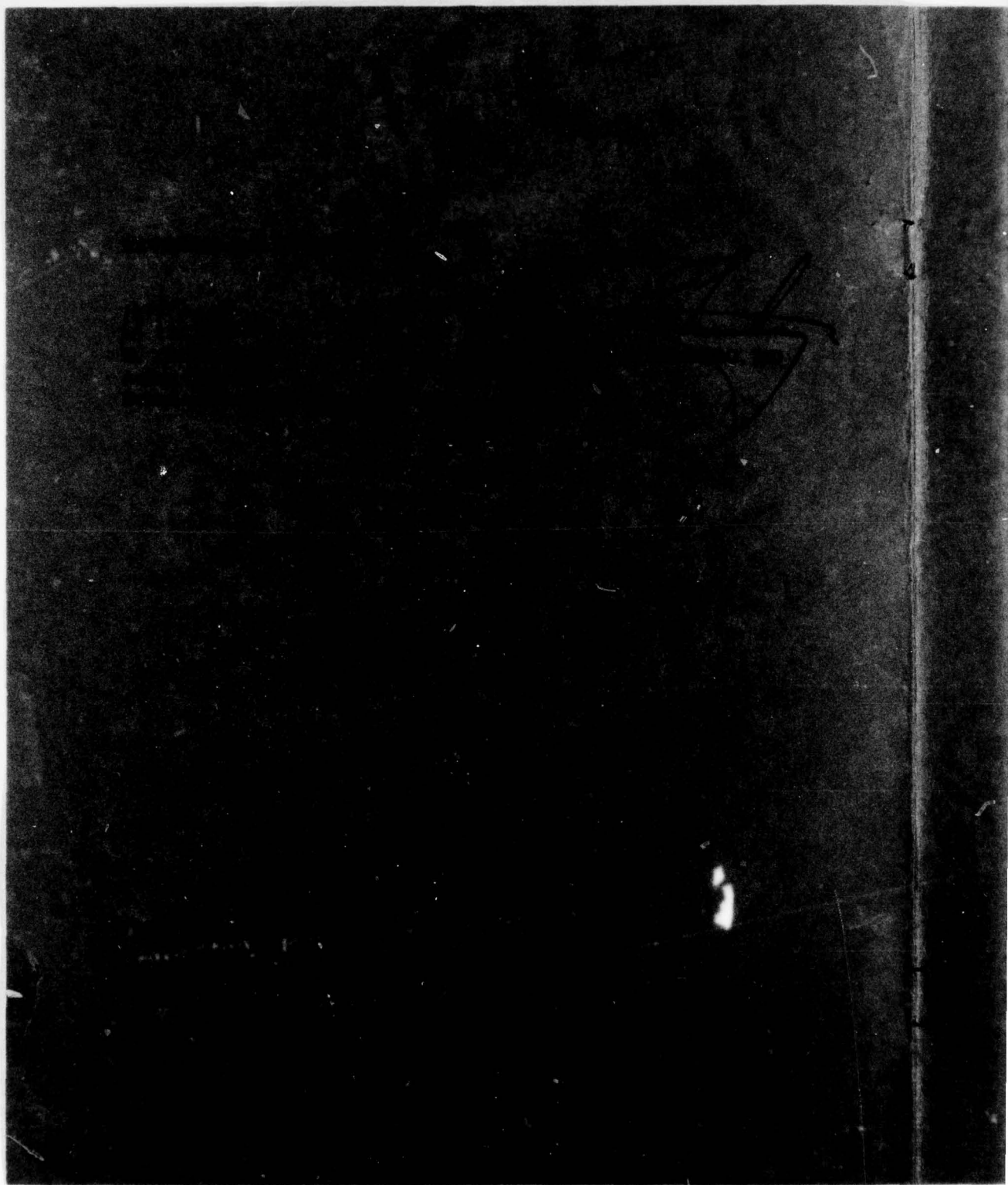


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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Upon detonation, nuclear weapons create an electromagnetic pulse (EMP) as well as blast, thermal and radiation energy. The EMP is known to have a deleterious effect on some types of electronic equipment, but it is unknown whether or not EMP has an effect on personnel. Most animal research data are negative, but, with few exceptions, the research was performed on untrained animals. The objective of this experiment was to evaluate the effects of repeated, high intensity EMP on the		

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electroencephalogram and performance of a highly trained rhesus monkey. A 12-kg male rhesus monkey was exposed to EMP at 266 kV/m, 5 pulses per sec, for 1 hour (18,700 pulses). The effects of EMP on Sidman avoidance behavior and on postexposure electroencephalogram were evaluated, and no significant changes were detected. An analysis of an EMP showed that it contained various frequency components extending from 0 Hz to 10^9 Hz. However, the pulse configuration was such that its power was mainly confined to the longer wavelengths (< 30 MHz). The lack of biologic effect was attributed to the fact that the wavelengths were long relative to the size of the monkey, and little energy deposition was likely to occur. In addition, the electric field was evenly distributed across all lower frequencies so that only a very small electric field component existed at any specific low frequency.

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SUMMARY
(Nontechnical)

Neurological and physiological reactions have resulted from exposures to a wide variety of low intensity electromagnetic fields. Electromagnetic pulse (EMP), an uncommon form of electromagnetic field, has been reported to cause easy fatigability, extreme irritability, aching joints and mild frontal headaches in people, although no changes were noted in blood count, blood chemistry or electrocardiogram. Field strengths in EMP exposure areas may be as high as 750 kilovolts/meter (kV/m), with diminished field strengths of less than 1 kV/m occurring in routine work areas. At times personnel may work closer to the source, thereby exposing themselves to field strengths greater than 1 kV/m.

Because of continuing concern that electromagnetic energy at certain intensities, frequencies and modulations may affect the central nervous system, a rhesus monkey was exposed to an EMP field with pulse characteristics comparable to industrial systems and at a field intensity and pulse rate vastly greater than those encountered in normal work areas. The effects of EMP on Sidman avoidance behavior and postexposure electroencephalogram (EEG) were evaluated, and no significant changes were detected. The lack of biologic effect was attributed to the fact that the wavelengths of the major EMP frequency components were long relative to the size of the monkey, and little energy deposition probably occurred.

PREFACE

Technicians W. N. Fry and J. P. Alligood were responsible for the day-to-day training and stabilization of the monkey, D. N. Stevens built the Plexiglas reclining chair and box, and E. L. Ross operated the EMP apparatus.

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INTRODUCTION

Neurological and physiological reactions have resulted from exposures to a wide variety of low intensity electromagnetic fields.^{3,10} Electromagnetic pulse (EMP), an uncommon form of electromagnetic field, has been reported to cause easy fatigability, extreme irritability, aching joints and mild frontal headaches in people, although no changes were noted in blood count, blood chemistry or electrocardiogram.^{7,14} Field strengths in EMP exposure areas may be as high as 750 kV/m, with diminished field strengths of less than 1 kV/m occurring in routine work areas. At times personnel may work closer to the source, thereby exposing themselves to field strengths greater than 1 kV/m.¹⁴ Pulses are characterized by rise times of 3 to 10 nanoseconds and pulse repetition rates from 12 pulses per second to 1 pulse per several minutes.

Animal experiments in high intensity EMP fields have generally yielded no detectable behavioral or blood chemical changes, but disrupted rat maze running has been reported in a field of 600 kV/m, single pulse.⁸ No general behavioral effects were observed in a stump tail macaque at < 500 kV/m, 8 pulses;⁷ no changes occurred in operant performance of a rhesus monkey at 600 kV/m, several pulses;⁷ no changes were noted in blood chemistry in dogs at 600 kV/m, 8 pulses;⁷ and no significant pathological changes were detected in rats in an EMP field for 38 weeks.¹⁷

An analysis of an electromagnetic pulse (EMP) shows that it contains various frequency components extending from 0 Hz to the gigahertz region (10^9 Hz). The more common electromagnetic fields (e.g., radar, television, radio, microwave) cover the same range in sinusoidal frequency, but are applied continuously or may be amplitude modulated in square wave pulses or at various sine wave frequencies. Absorption of electromagnetic energy is not a simple phenomenon, but varies with the frequency of the radiation and the size and shape of the biologic target. When absorption of electromagnetic energy occurs, it is inevitably associated with increased temperatures. However, interactions with the mammalian central nervous system can be produced by oscillating

fields without significant heating of tissues, i. e., temperature changes less than 0.1°C .¹ Fields as low as 4 V/m, when oscillating at 2 to 12 Hz, have affected human reaction times.⁶ Oscillating magnetic fields as slow as 0.2 Hz have also affected human reaction times,⁴ and low intensity magnetic fields rotating at 0.5 Hz have altered rat conditioned behavior.¹³ At the high end of the radio frequency spectrum (above 300 MHz), rat behavior and electroencephalogram have been altered by microwave exposures of less than 10 mW/cm^2 .^{9,11,16,18} All of these high and low frequencies are contained in an EMP.

Because of continuing concern that electromagnetic energy at certain intensities, frequencies and modulations may affect the central nervous system, a rhesus monkey was exposed to an EMP field with pulse characteristics comparable to industrial systems and at a field intensity and pulse rate vastly greater than those encountered in normal work areas. The effects of EMP on Sidman avoidance behavior and postexposure electroencephalogram (EEG) were evaluated.

METHODS

A 12-kg male rhesus monkey (Macaca mulatta) was exposed to EMP at 266 kV/m, 5 pulses per second, for 1 hour (18,700 pulses). An intensity of 266 kV/m was chosen to avoid the sensory cues that might accompany the corona that appeared at the extremities at higher intensities.

The EMP wave shape (Figure 1) produced by the AFRRI EMP generator² can be described by a function of the form

$$e(t) = E_0 (e^{-\alpha t} - e^{-\beta t})$$

where $\alpha = 1.82 \times 10^6$, $\beta = 2 \times 10^8$. The Fourier transform of $e(t)$ gives a means of analyzing the amplitude versus frequency characteristics of the pulse:

$$e(t) = E_0 (e^{-\alpha t} - e^{-\beta t})$$

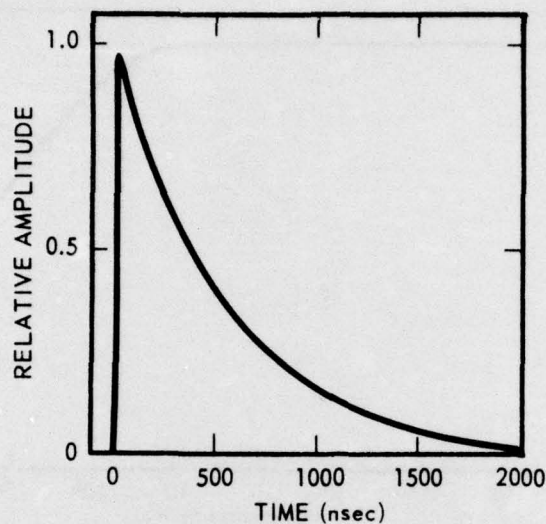


Figure 1. Wave form of EMP

$$E(w) = \int_0^{\infty} E_0 (e^{-\alpha t} - e^{-\beta t}) e^{-j\omega t} dt$$

$$E(w) = \frac{E_0 (\beta - \alpha)}{(\alpha + j\omega) (\beta + j\omega)}$$

where $\omega = 2\pi F$ angular frequency

$$|E(f)| = \frac{E_0 (\beta - \alpha)}{(\alpha^2 + 4\pi^2 F_0^2)^{1/2} (\beta^2 + 4\pi^2 F_0^2)^{1/2}}$$

This gives a frequency versus amplitude spectrum as shown in Figure 2. To find the average power density in a spectrum above frequency F_0 , assume a simplified version of the pulse with instantaneous rise time:

$$e(t) = E_0 e^{-\alpha t}$$

$$\text{then } h(t) = \frac{E_0 e^{-\alpha t}}{120\pi}$$

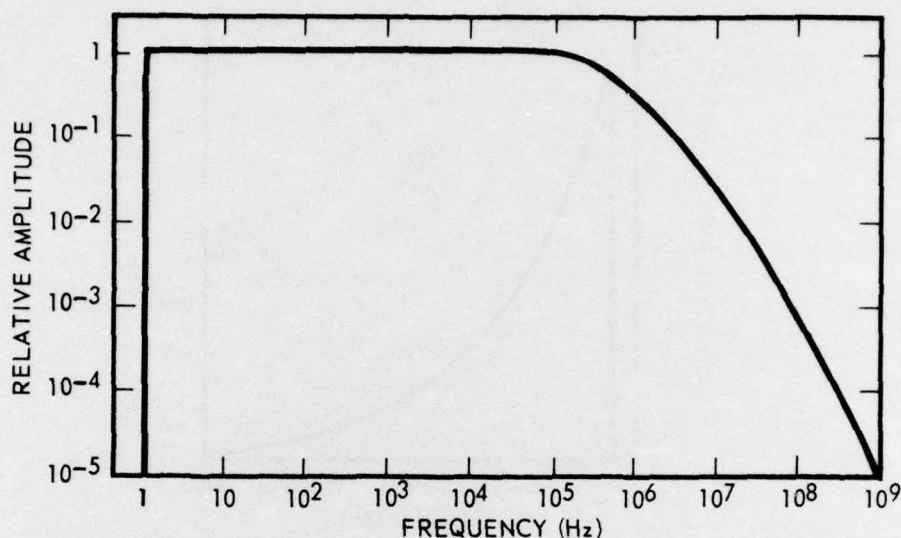


Figure 2. Fourier frequency distribution of EMP

$$\text{and } E(w) = \frac{E_0}{\alpha + jw} \quad H(w) = \frac{E_0}{120\pi (\alpha + jw)}$$

and the average power densities above a frequency F_0 are computed from

$$P(F_0) = \frac{1}{\pi} \int_{2\pi F_0}^{\infty} P_0(w) dw$$

$$\text{where } P_0(w) = \frac{E(w)H^*(w)}{T} = \frac{E_0^2}{120\pi T} \frac{1}{(w^2 + \alpha^2)}$$

where T = time between pulses.

The average power density in the spectrum above F_0 is then:

$$P(F_0) = \frac{1}{\alpha} \frac{E_0^2}{120\pi^2 T} \left(\frac{\pi}{2} - \tan^{-1} \frac{2\pi F_0}{\alpha} \right).$$

These formulas give the EMP properties shown in Table 1.

The monkey was seated in a reclining chair in an opaque Plexiglas box fitted between the horizontal plates of the EMP transmission structure. A Lucite lever for recording Sidman responses entered through the side wall of

Table 1. EMP Radiation Exposure Field

1.	Peak Field Strength (kv/m)	266
2.	Pulse Duration (nsec)	561
	a. 10% - 90% rise time (nsec)	11
	b. $\frac{1}{e}$ Fall Time (nsec)	550
3.	Peak Power Density (W/cm ²)	1.88×10^4
4.	Frequency Spectrum (MHz) of components above -50 dB	0-1000
5.	Average Power Density (mW/cm ²)	
	a. Total	25.3
	b. Above 100 MHz	.048
	c. Above 30 MHz	.158

the Plexiglas box. During Sidman performance sessions, the monkey could indefinitely avoid a 0.2-sec shock as long as the interval between lever pulls was less than 10 sec. The Sidman performance sessions lasted 10 min each, with a 5-min rest period between sessions. The EMP exposure began midway in the second Sidman session, and terminated 1 hour later, midway in the sixth session. The EEG was recorded immediately before the EMP was turned on, but during the actual EMP exposure the amplifier inputs were grounded and the wires from the monkey to the amplifiers were disconnected. Immediately after the EMP was turned off the wires were reconnected, amplifiers were turned on, and postexposure EEG was recorded.

Electroencephalographic leads were left fronto-occipital and right temporo-occipital. Electrodes were chronically implanted stainless steel screws that rested on the dura mater. Epochs for frequency distribution analysis were chosen on the basis of time into the experiment. The EEG was not examined prior to epoch selection.

RESULTS AND DISCUSSION

Exposure to 18,700 pulses of 266 kV/m electromagnetic pulsed radiation (5 pulses per sec, 1 hour exposure) caused no significant changes in electroencephalogram (EEG) or Sidman avoidance behavior. Postexposure EEG frequency spectrum shifted slightly toward the lower frequencies (Figure 3), and total EEG power diminished about 30 percent. These changes occurred on both the control and exposure days, and therefore could not be attributed to the EMP exposure.

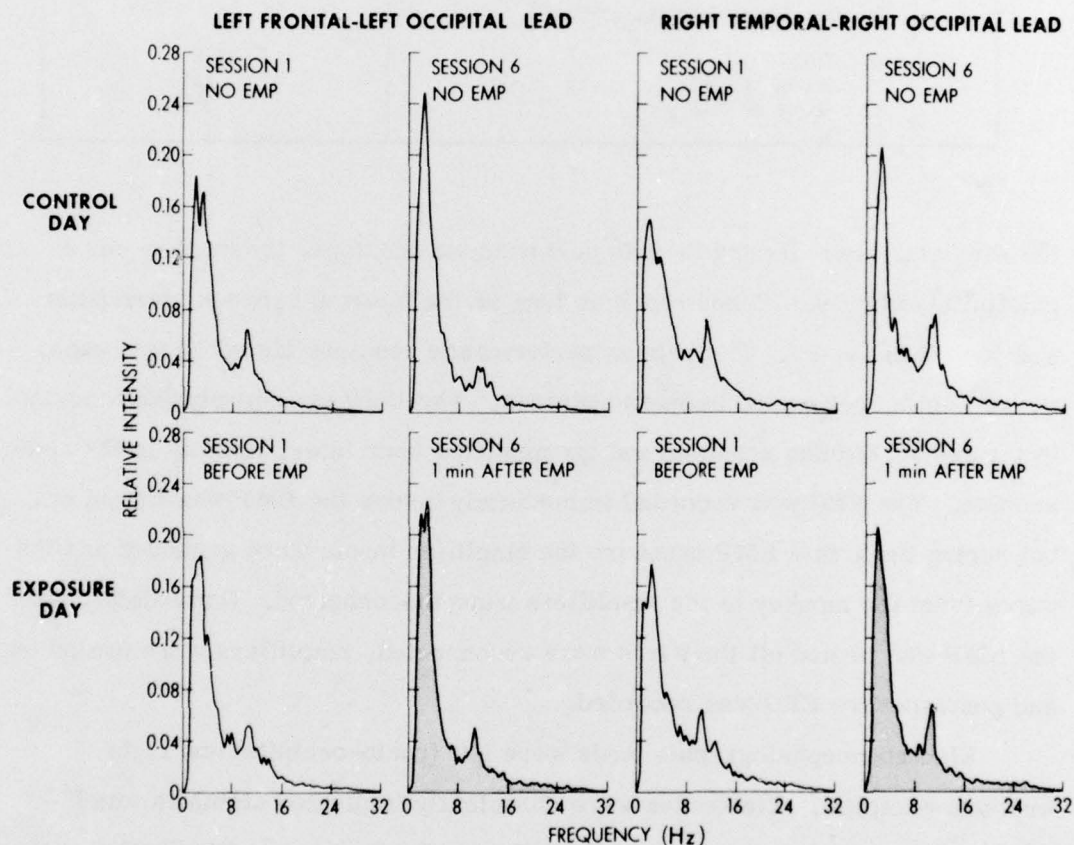


Figure 3. Effect of EMP on EEG frequency distribution. Between Sidman session 1 and session 6, on both control and exposure days, EEG power shifted toward the slower frequencies. Areas under all curves were normalized. Postexposure curves are shaded.

Sidman avoidance rate was 21.3/min on the control day and 21.5/min during the EMP exposure, with no departure in normal response pattern when shifting between work-rest, rest-work periods. The monkey received one shock on the control day (during Sidman session 4), and two shocks on the exposure day (during Sidman sessions 2 and 6). Appropriate accelerated postshock responding occurred after each incident.

The main issue when considering the possibility of electromagnetic radiations affecting biological systems is whether or not energy is deposited in the body, or focally in a specific part of the body. It has been shown^{12, 15} that absorption of electromagnetic energy in spheres with tissue-like dielectric properties is dependent on the size of the sphere and the wavelength of the energy (or EMP time rate of change).⁵ As the sphere size decreases, or the wavelength increases, energy deposition is markedly reduced. According to one analysis,¹⁵ when the wavelength is less than three times the circumference of the target sphere, significant energy absorption occurs, while minimal absorption occurs at longer wavelengths. For example, a 100-MHz signal has a 3-meter wavelength and would be expected to deposit a significant portion of its energy into a tissue-like target sphere with circumference greater than 1 meter. For a 30-MHz signal, with a 10-meter wavelength, the sphere would have to be greater than 3.3 meters in diameter for significant energy absorption to occur. As seen in Table 1, virtually all of the EMP energy was contained in frequencies below 30 MHz, where wavelengths are long compared to the circumference of the monkey, especially when compared to the circumference of the head. Thus, minimal energy deposition would be expected to occur in a biologic target the size of a monkey.

An alternative to the sphere model is to treat the biologic target as a quarter wave of half wave dipole antenna. Effective electromagnetic interaction occurs when the antenna length is one-quarter wavelength ($1/4\lambda$), or multiples thereof. For a 1-meter long monkey, the dipole or quarter wave model predicts that wavelengths in excess of 4 meters (frequencies less than 75 MHz) would be

ineffective in depositing significant energy into the animal, even if the animal could absorb energy to the same extent as an antenna. Since EMP contains virtually no power at frequencies above 30 MHz, much less above 75 MHz, the dipole antenna model again predicts no EMP interaction with subjects the size of a rhesus monkey.

In spite of the predictions of the sphere and dipole antenna models, that negligible energy deposition will occur when wavelengths are long when compared to the subject, magnetic fields oscillating as slow as 0.2 Hz have been reported to affect human reaction times,⁴ although slightly higher oscillation rates (6 to 12 Hz) may be more effective.⁶ These changes have been noted at field strengths as low as 2 to 10 V/m.^{1,6} The pulse rate of the EMP at AFRRRI was 5 pulses per second, and there were sine wave Fourier components of the pulsed signal in the range of 1 to 20 Hz, introducing a possibility for biologic interaction due to slow pulse rate or low frequency magnetic fields. However, it should be noted that the maximum amplitude of any specific low frequency component was very small:

$$E(f) = \frac{E_o (\beta - \alpha)}{(\alpha^2 + 4\pi^2 F_o^2)^{1/2} (\beta^2 + 4\pi^2 F_o^2)^{1/2}}$$

$$\cong \frac{E_o (\beta - \alpha)}{\alpha \beta}$$

at low frequencies

$$E(f) \cong .14 \text{ V/m.}$$

If low frequency fields can affect performance, it seems probable that EMP did not affect the monkey's performance because of the broad distribution of the energy across all the low frequencies, so that the average electric field was only 0.14 V/m at any specific frequency.

In addition to other effects, startle responses have been reported at the instant of electromagnetic pulsing (<600 kV/m) in both rats⁸ and a rhesus monkey,⁷ and microwave on-off transition (possibly related to EMP) has caused a

nonspecific arousal effect in intact animals and isolated cortical strip preparations.¹⁰ These effects were not demonstrated in this experiment, as there was no momentary change in Sidman lever pressing rate when the EMP started (Figure 4), or when it was turned off.

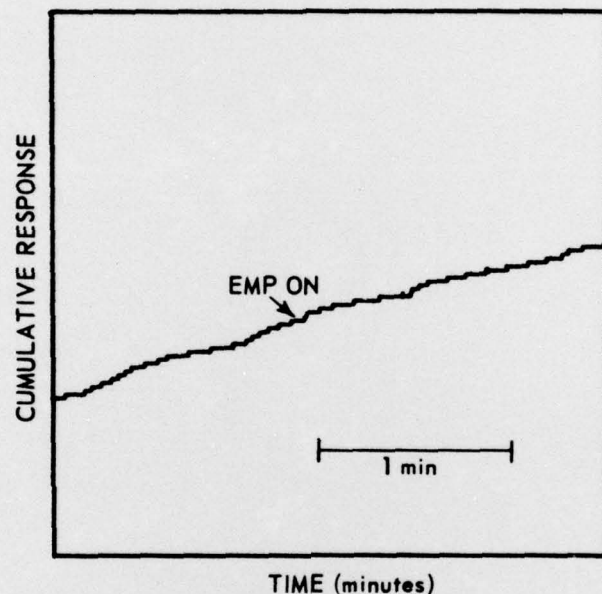


Figure 4. Cumulative response chart, middle segment of Sidman session 2, at moment EMP turned on. Chart increments one step for each lever pull. Note lack of task disruption when EMP began.

It appears, then, that EMP has characteristics that confine its power to the longer wavelengths (< 30 MHz), so that energy deposition into smaller biologic targets is minimal. In addition, the electric field is evenly distributed across all the lower frequencies so that only a very small electric field component exists at any specific low frequency. Implications are that, to extrapolate animal derived EMP data to man, either animals as large as man should be used, or the EMP rise time must be shortened to adjust the Fourier

frequency components to higher frequencies. The experimental model should retain the wavelength to body size relationship of man in an EMP field.



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